RIT

At the Edge of a Black Hole

Theory, observation, and the limits of what we can see

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Introduction into Astrophysics

Authentic EHT image: M87* (2019) | EHT Collaboration / ESO

What is an event horizon?

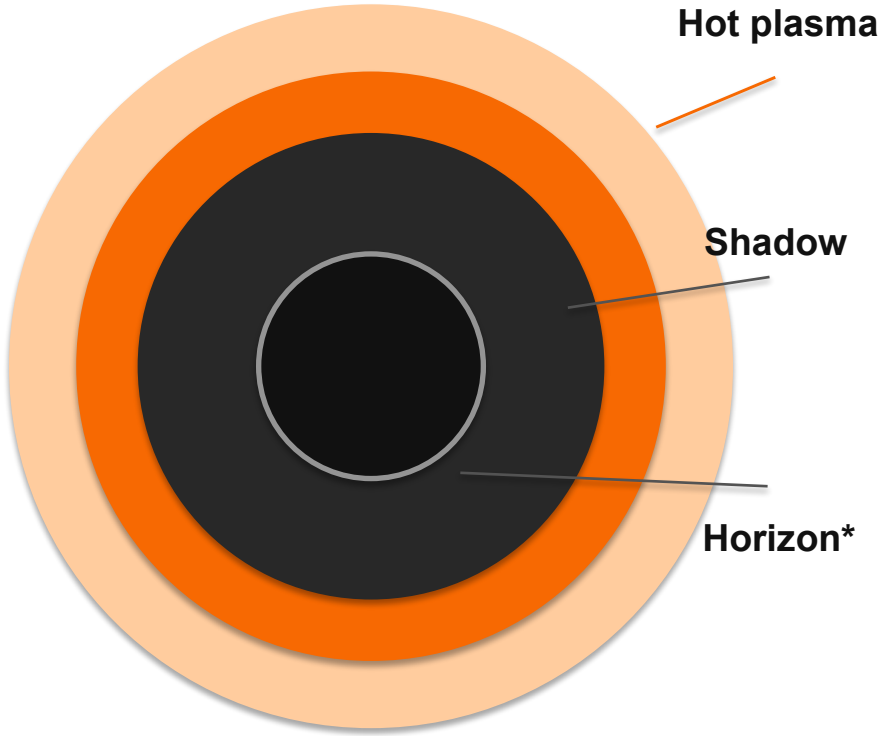
Three different things: the horizon, the shadow, and the glow.

- **Event horizon**

  The boundary past which light cannot reach distant observers.
- **Black hole shadow**

  The dim central region associated with light capture and lensing.
- **Bright emission ring**

  Radio waves from hot plasma close to, but outside, the horizon.



$$r_{\square} = 2GM / c^2$$

G = gravitational constant M = black hole mass c = speed of light

Source: 't Hooft, Introduction to the Theory of Black Holes; EHT Collaboration (2019).

What does theory predict?

Spacetime shapes photon paths; the plasma determines how the emission looks.

- **Gravitational lensing**

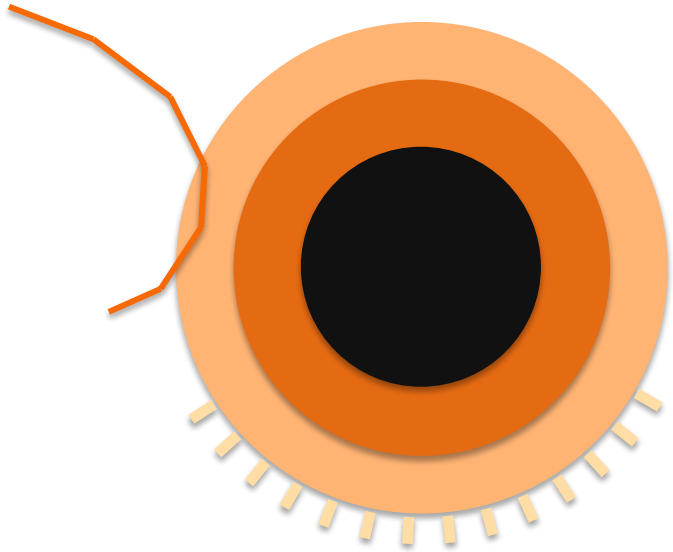
  Light paths curve strongly and some photons are captured.

- **Orbiting hot plasma**

  Fast motion can make one side of the bright ring appear stronger.

- **Magnetic fields and variability**

  Polarization and changing brightness reveal plasma behavior.



Qualitative illustration

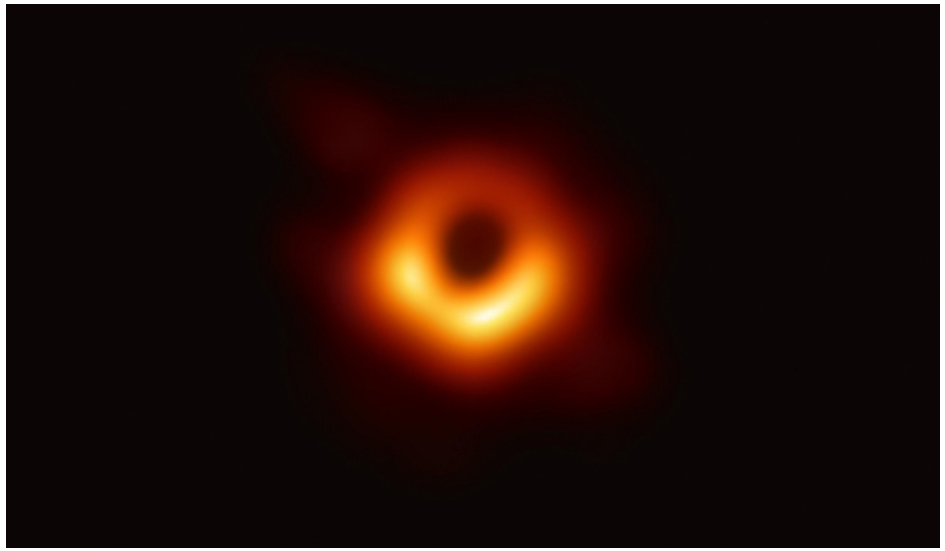
Light bending + asymmetric emission

Sources: EHT Collaboration (2019); Machida & Matsumoto (2003, preprint 2002).

M87* and Sagittarius A*

Both are reconstructed 1.3-mm radio images of hot plasma—not visible-light photographs.

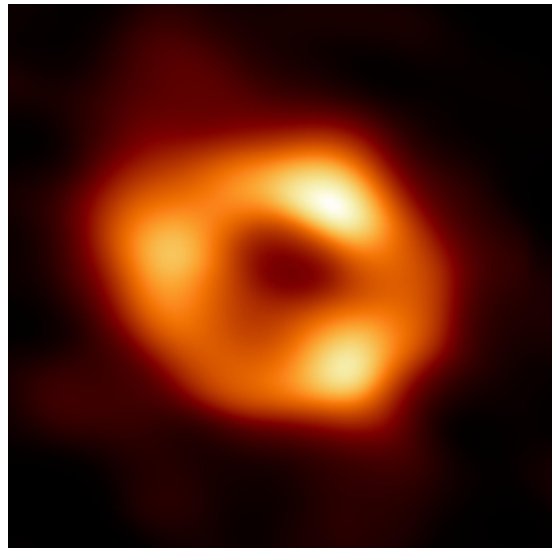
M87* | 2019



≈ 6.5 billion solar masses

Ring diameter: 42 ± 3 μas

Sagittarius A* | 2022



≈ 4 million solar masses

Ring diameter: 51.8 ± 2.3 μas

Images: EHT Collaboration / ESO (2019, 2022). μas = microarcseconds; masses and rings from EHT papers.

How did astronomers make these images?

Very long baseline interferometry (VLBI): many telescopes working as one Earth-sized array.

- **Observe together**

  Telescopes around Earth target the same source.
- **Timestamp signals**

  Atomic clocks align the radio recordings.
- **Combine the data**

  Correlators recover interference information.
- **Reconstruct an image**

  Algorithms infer a plausible image from sparse samples.



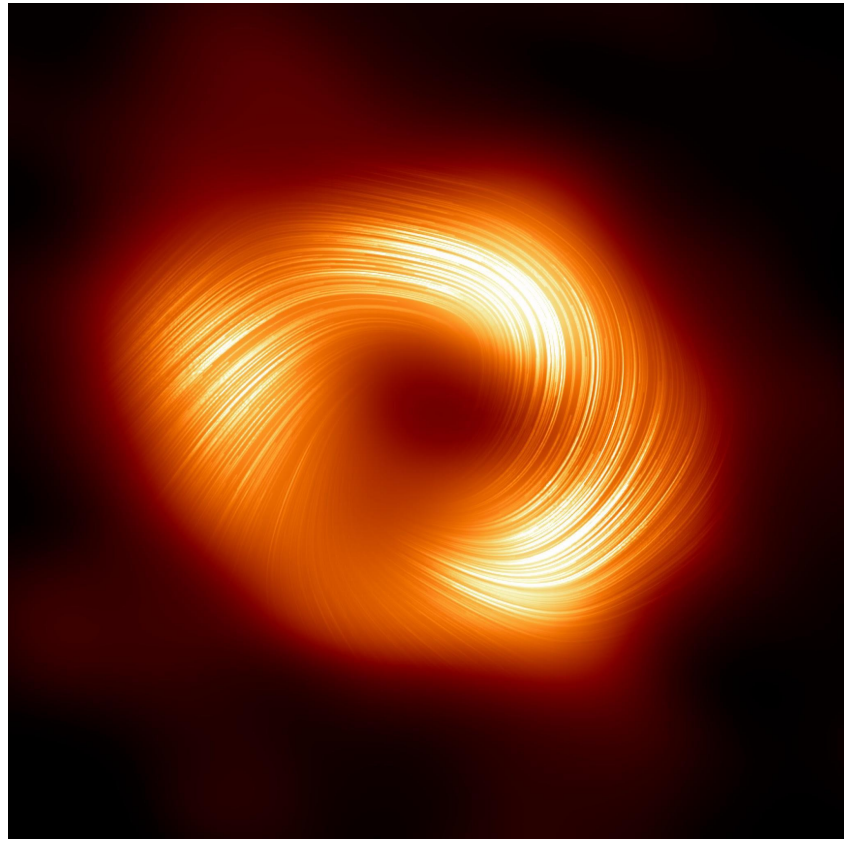
EHT stations, with the original 2017 network highlighted.

Array map: ESO / M. Kornmesser (2022). This is interferometric reconstruction, not an ordinary photograph.

Which predictions have been supported?

The observations agree with key predictions, but plasma physics remains model-dependent.

- **Ring and shadow**
  Size and central dimming are consistent with lensing.
- **Asymmetric emission**
  Brightness structure is compatible with fast plasma.
- **Polarization**
  Patterns imply organized magnetic fields.
- **Time variation**
  Sagittarius A* changes while it is observed.



Polarized Sagittarius A* (EHT, 2024)

Sources: EHT Collaboration results (2019, 2022, 2024); ESO / EHT polarized image.

Why the picture is still incomplete

Four limits make definitive tests of event-horizon physics harder.

- **Tiny angular size**
  The black-hole rings are only tens of microarcseconds wide.
- **Atmosphere and instruments**
  Calibration errors and scattering blur the radio signal.
- **Sparse telescope coverage**
  The array measures only a fraction of the possible baselines.
- **Rapidly changing gas**
  Sagittarius A* can evolve during the observations.

An image reconstructed from incomplete measurements must be checked against multiple algorithms and models.

Sources: EHT Collaboration (2022); EHT imaging and VLBI methods.

What could the next EHT show?

A larger array could move us from static images toward time-resolved views.

Already demonstrated

2024–2025

345 GHz VLBI detections and frequency-phase transfer tests.

Under development

2026

Additional station planning, new telescope sites, and expanded array capability.

Future research goal

Early 2030s

More sensitive, multi-band observations that may capture changing plasma flows.

More stations + higher sensitivity + multiple frequencies = more precise tests of plasma and gravity.

Sources: ngEHT science and news (2024–25); CfA / Harvard & Smithsonian (Sep. 2026).

Big takeaways

- **General relativity predicts**
  A lensing-related shadow and characteristic light paths.

- **The EHT measures**
  Ring sizes, variable brightness, and polarization near black holes.

- **The next step**
  Time-resolved imaging to understand moving, magnetized plasma.

What could we discover when we can watch matter move near the edge of a black hole?

Images and observational results: EHT Collaboration (2019, 2022, 2024).

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Thank you.